DG C37.012 Notes of interest Spring 2011 Switchgear Meeting Set

Discussion Group C37.012 met 16 May 2011 in Lake buena vista, FL. with 21 prospective members and 29 guests.

We reviewed the items on the Agenda prepared by Anne Bosma.

Decisions:

1) to go with the proposed new title, scope and purpose.
2) Removing the “ANSI” substituting IEEE,
3) making the word order parallel to other titles.
4) It was further suggested to have the word order in the scope parallel the new title.

Anne will apply for a PAR by circa September 1, 2011.

Roy Alexander Presented his revised prestrike arc shockwave theory (attached below)

Many private discussions ensued about this presentation after the “official meeting was adjourned, mostly surrounding some specific details as spped of a shockwave can be faster than speed of sound.

Meeting adjourned, after no one volunteered to take on any sections of the document.

Grace & Peace

Roy Alexander
Acting Chair DG C37.012

Prestrike Arc Shockwave Theory Revision 1 05/13/2011

For interrupters using gaseous interrupting media (including oil breakers which actually interrupt current in H_2) We know that an arc will be struck in gas prior to contact touch.

Consider a prestrike arc of cylindrical shape with radius r. When the arc channel is fully ionized, current flow can be increased either by “growing” the arc, so that its cross sectional area is increased and the number of available charge carriers increases, or by moving the charge carriers faster. To move the charge carriers faster a higher arc E field is required and a corresponding higher arc voltage per unit length. The size of the arc (uninhibited by a physical barrier) and with a constant E field is determined by the charge carrier density and the current magnitude. For SF_6 at 4 bar (somewhat rarified by reverse puffer action) assume a current density in the arc of $640A/mm^2$.

Since the speed of sound in SF_6 is 140m/s, if a shock wave is to result from sudden radial growth of an arc, the radius must increase faster than 140 m/s. i.e. dr/dt>140m/s.

For a small radius this occurs very rapidly. In fact a small shock wave will form immediately and the arc will be constrained by the speed of sound. In order to increase the current flow faster, the arc voltage will have to increase until the shock wave passes adding more charge carriers. After passage of the shock wave, the rate of growth of the arc radius will be proportional to the square root of the rate of growth of the current ($dr/dt \propto \sqrt{(di/dt)}$) The inrush/outrush capability can be defined as $\sqrt{I} \times f$ = a constant .

For small radius arcs this occurs at lower currents. This can be observed with spark discharges in air. The breakdown occurs in about 100ns with a small radius and creates the pop or bang we hear.

For an arc in an SF6 breaker, with radius 10mm (somewhat smaller than typical 31.5kA circuit breaker nozzles) the time to achieve a 10mm diameter would be .01m/140m/s = 71 µs.

The current magnitude to support an arc radius of 10mm would be $3.14159 \times (10\text{mm})^2 \times$ 640A/mm = 200kA .

The key to shock wave restraint of the arc is how fast the initial current reaches its peak.

I am assuming the shock wave front must "fit" inside the nozzle and beyond this radius the arc would increase to slowly to sustain the shockwave. The rough equivalent frequency can be determined as follows:

The peak current occurs in 71µs so the period is 4 x 71µs = 284µs for an frequency of 1/284µs = 3.5kHz at 200kA an < 3.5kHz the shock wave will "fit in the nozzle. As current is reduced the frequency can be increased by $\sqrt{(I_1/I_2)}$
Additionally to keep peak arc power constant the arc voltage can increase in inverse proportion to the current.

The result is we obtain the relation $I \times f^{2/3}$ = a constant.

To evaluate the constant $200\text{kA} \times (3.5\text{kHz})^{.666} =$ 460 with I in kA, and F in kHz

Making the assumption that the capability will be roughly proportional to the SC rating

K_{SF6} = 14.6 x SC rating

For Oil on closing there is no difference between a "definite purpose" and a "general purpose breaker" so we have the accepted values of 15kA; 4.25kHz for bulk oil breakers based on a 50kA SC peak rating. So $k_{OCB} = 15\text{kA} \times (4.25)^{.666}$ /35kA eq. rating = 1.12 x SC rating in kA.

For oil breakers it is much more difficult to judge what the shock radius should be because of the oil being an incompressible fluid. However we have tested capacitor inrush values for definite purpose breakers and we have short circuit tests.

Proposed method for determining Capacitive Inrush (outrush) capability of circuit breakers. (Rev 1)

In no case should the Inrush/outrush current exceed 2.6 x the rms short circuit rating of the breaker (i.e. close and latch peak current)

Based on the prestrike arc shockwave theory for resonant circuits:

$I \times f^{2/3} = k$

Where: I = the allowable peak current (KA)
f = the natural frequency of the circuit (kHz)
k = a constant different for each major interruption technology

For bulk oil breakers: k=1 x (rms short circuit rating)

For SF_6 breakers : k= 14.6 x(rms short circuit rating)

For Vacuum breakers wishing to attain Class C2 I<6kA regardless of frequency

For Vacuum breakers wishing to attain class C1 I< 20kA regardless of frequency

Roy W Alexander
13 May 2011